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Deriving an exergetic economic production quantity model for better sustainability

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ABSTRACT

Businesses strive to be sustainable because of internal and external pressures. To examine sustainability, firms may use different methods of analysis. Extended Exergy Accounting (EEA) - a resource based evaluation method - is such a tool used to examine environmental, social, and economic sustainability. This paper re-examines the economic production quantity (EPQ) model, in an attempt to reflect the needs of sustainability. The paper uses EEA and the laws of thermodynamics to measure the sustainability of a production-inventory system and finds that in some situations sustainability can be profitable. EEA measures the value of a commodity, based on the consumption of the natural and physical resources as opposed to the classical EPQ model, which uses monetary cost. Measuring the exergy consumed during the production of a commodity shows that the exergetic model developed can deliver better sustainability and profitability than the classical EPQ. This should further encourage companies to move towards sustainable strategies. The results suggest that governments, individuals and other organizations should encourage companies to move towards sustainable strategies.

1. Introduction

The Economic Production/Order Quantity (EPQ/EOQ) model has been widely used by academicians and practitioners [1]. Many researchers have modified the model to fit specific manufacturing scenarios. Andriolo et al. [2] and Bushuev et al. [3] provide concise reviews of these works.

Some researchers have called for new thinking about inventory and logistics management. For example, Chikán [4] argued that classical models no longer describe today's inventory and logistics situations because of the fundamental changes in business, while Bonney and Jaber [5] advocated the need to develop environmentally responsible inventory models. Jaber et al. [6] suggested that one could improve production systems by applying the first and second laws of thermodynamics to reduce system entropy (disorder). They developed and incorporated a new cost component into the EPQ/EOQ model, "entropy cost", which may represent the sum of the hidden costs inherent in inventory systems that classical models do not consider. Jaber et al. [7] introduced the concept of exergy cost, to represent the amount of useful energy wasted.

"Exergy Analysis" is a promising method that has been used to reduce the depletion of natural resources and the excessive use of energy [8]. It analyzes the inputs and outputs of a system along with the wasted (lost/unused) exergy in order to improve the system's efficiency.

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Production and inventory activities are among those responsible for greenhouse gas (GHG) emissions. The quantity of GHGs (especially CO_2) emitted is sometimes used to evaluate the environmental performance of a business or a firm. An increase in environmental awareness and a desire to control GHG emissions means that various schemes of pricing emitted carbon have been introduced in recent years. The aim of such schemes is to encourage businesses and individuals to seek and utilize tools and strategies that reduce carbon emissions. Andriolo et al. [2] and Bushuev et al. [3] report investigations into how to reduce GHG emissions in inventory and logistics systems. In this regard, exergy analysis has sometimes been used to capture the exergetic cost of a GHG emission resulting from energy generated from non-renewable resources.

This paper introduces an exergetic version of the EPQ model to compute the amount of exergy consumed when producing and storing a product, and uses it to select the proper level of sustainability. The paper also uses thermodynamic concepts to derive a new exergetic sustainability indicator for a production-inventory system to answer whether "can sustainability be profitable?" In particular, the paper uses the Extended Exergy Accounting (EEA) method introduced by Sciubba [9], covering the basic production factors that are not usually considered in exergy analysis at the socio-economic scale, i.e., capital, labor, and environmental remediation [10]. Seckin et al. [11] and Rocco et al. [12] report other relevant and interesting studies. The first, [11], employs the extended exergetic efficiency, evaluated as the ratio of the sectoral output to input fluxes, to show the unsustainable structure of the transport sector in Turkey, while the second [12] graphically presents the exergy cost function and the extended exergy consumed by a system during its life cycle. The authors claim that such graphs could be useful to compare the "degree of unsustainability" of alternative production lines and/or to determine the unsustainability of a commodity, as reflected by the amount of non-renewable resources embedded in a product.

The rest of this paper is organized as follows. Section 2 presents a brief background on exergy, exergy analysis and exergetic costs. Section 3 introduces the concept of an exergetic EPQ model. Section 4 briefly explains the exergetic sustainable indicator and its links with the concept of thermodynamic efficiency. Section 5 presents a numerical analysis, results and discussion, while Section 6 provides some concluding remarks.

2. Exergetic costs and the flow of a commodity

2.1. A brief background on exergy

"Exergy" is a thermodynamic term representing the maximum amount of useful work a commodity or a system can produce/generate at a given state when interacting with a reference environment (often the actual environment) at a constant condition. Loosely, exergy is the useful amount of energy obtainable from a system. The sustainability of a system is linked to exergy losses from using non-renewable forms of energy [13].

Exergy analysis is a powerful technique that can assess and improve the efficiency of a process, device or system, and enhance its environmental and economic performance. Nowadays, industrial and governmental organizations worldwide increasingly use exergy analysis to improve energy efficiency [14].

Fig. 1 illustrates an arbitrary production system with input streams that include labor, energy, materials, equipment, etc. These streams are analogous to the work inputs into a thermal system that allow heat transfers from one heat reservoir to another at a higher temperature. In addition, there is an output stream that includes one or more of the final products

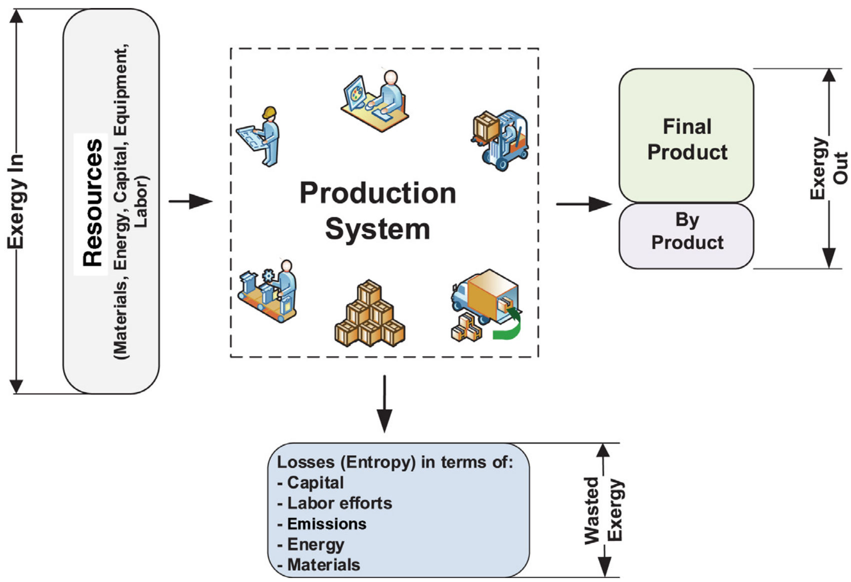

Fig. 1. Input and output streams of a production system.